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CHANGES IN THE AREA OF ARCTIC SEA ICE 1966 TO 1974

By R. M. SANDERSON

Summary. This article presents the results of an investigation into recent changes in area of the northern hemisphere sea ice. It is shown that in both the winter and summer months the mean area for the period 1972–74 is slightly less than that for the period 1969–71. It is suggested that this decrease is also applicable to the two consecutive 4-year periods between 1967 and 1974.

Introduction. For some considerable time there has been a demand (from meteorologists, climatologists and others) for information on the year-to-year variability of sea ice in the northern hemisphere. Previously it has not been possible to meet this demand because ice limits around the whole region have not been sufficiently well defined to permit year-to-year comparisons to be made. The introduction of polar-orbiting meteorological satellites early in 1966, however, has allowed ice limits to be defined much more accurately, so that such comparisons can now be made. This investigation into variations in the areal cover of the Arctic sea ice since early 1966 was therefore undertaken.*

Data. To determine the area under sea ice the limit of 7/10 concentration was deliberately chosen since high concentrations of sea ice are of greater importance to meteorologists and climatologists in considering albedo and surface temperatures than are more broken ice conditions. Sea-ice limits of 7/10 were obtained from end-of-the-month sea-ice charts since early 1966. The charts used were those published by the Meteorological Office,[1] which are on a scale of approximately 1:21½ million and cover the area shown in Figure 1. They are based primarily upon data for the last 10 days of the month which means that only about one-third of the daily data are used in their construction. However, since ice-edge movements are generally very slow, it is considered that these charts are sufficiently representative of the total data to reveal any significant year-to-year changes in the area of sea ice.

The investigation was limited to the months of February, March and April, when the ice reaches its greatest extent, and to August and September when it

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* Since this paper was received, the following account of further relevant investigations has been published: DICKSON, R. R., LAMB, H. H., MALMBERG, S.-A. and COLEBROOK, J. M.; Climatic reversal in northern North Atlantic. *Nature, London,* **256,** 1975, pp. 479–482 (the issue of 7 August).

reaches its least extent. In the remaining months the ice edge is either advancing or retreating, according to the season, at varying rates which would tend to obscure any long-term trend in areal extent.

Over the Bering and Okhotsk Seas the data are available only from April 1968.

Method. The area under at least 7/10 cover of sea ice throughout the period of the survey (1966–74 in the 'Atlantic' sector and 1969–74 in the 'Pacific' sector) was determined for each of the five months investigated. It was found in each case by drawing the inner envelope of the lines of 7/10 cover in individual years given on the end-of-the-month charts. The area of 'permanent' ice cover each month was then calculated by counting the number of 1° 'rectangles' in each 1° latitude band, multiplying this figure by an appropriate factor to convert to areas in 10⁶ km², and summing for all latitude bands.

The variability of sea ice from year to year may be determined quantitatively by calculating the areas between the edge of the 'permanent' ice, and the line for 7/10 cover in individual years. This was done for each year of the survey using 1° rectangles in the manner described above. (For the purpose of this investigation, open water areas enclosed within areas at least 7/10 covered by ice were disregarded; they are too small to have any significant effect on the results.)

The edges of 'permanent' 7/10 ice cover, or the 7/10 minimum limits, for February and August are shown in Figure 1. The actual 7/10 ice edge for February 1972 is also displayed in order to give some indication of the area outside the 7/10 minimum limit for that particular year.

In order to permit a study of the relationship between ice conditions in one part of the hemisphere with those elsewhere, the areas under ice were tabulated by sectors. For the winter months the sectors were chosen to coincide with the various ice regimes around the Arctic, i.e. East Canada, Greenland Sea (east coast of Greenland and eastwards to 15°E), Barents Sea (including White Sea and Baltic), Bering Sea and Okhotsk Sea (see Figure 1). In the summer months, when the greater part of the ice edge lies within the Arctic Ocean, the ice cannot be divided into regions in this way. In August and September the sectors (0° to 90°E, 90°E to 160°E, 160°E to 130°W, 130°W to 85°W, 85°W to 0°) were chosen simply to facilitate the calculation of areas.

The area covered by the published monthly chart does not include the whole of the Pacific region affected by ice. The 'off-chart' parts of the Bering and Okhotsk Seas are shown in Figure 1. For these missing areas the 7/10 minimum and overall mean limits were drawn (from earlier post-war data) and the area between them was added where appropriate to each monthly area. The minimum, mean and maximum limits (the maximum being included to show the total variability) are shown for these areas in Figure 1. The error in using the 'mean' area for each month will be almost negligible since these 'off-chart' areas are relatively very small and the variability, especially in the eastern Bering Sea, is also small.

Results. The 1969–74 mean total areas under ice over the whole Arctic region are shown by months in Table I, which also gives the 1969–71 and 1972–74 means and the percentage decrease in mean area from the former to the latter 3-year period. The highest and lowest values and their departures from the 1969–74 mean, expressed as percentages, are also given. The mean values for
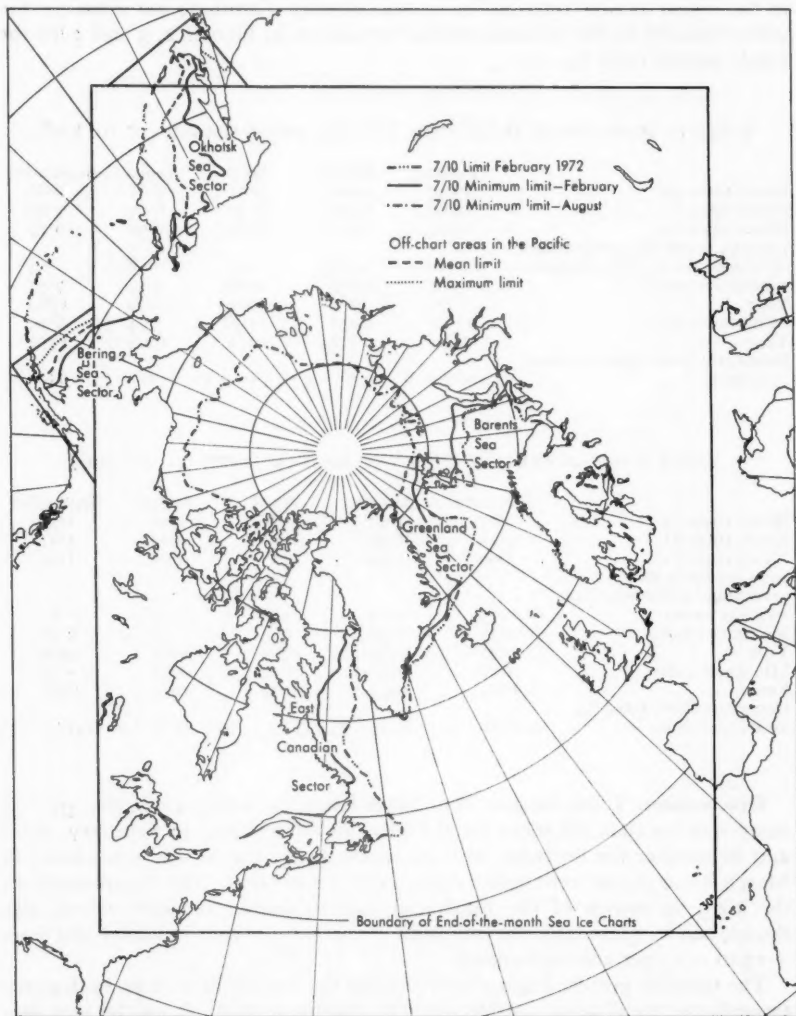
FIGURE I—MAP SHOWING LIMITS OF 7/10 SEA ICE PER I° 'RECTANGLE'

Note. The February 1972 limit coincides with the minimum limit in the western Bering Sea.

those parts of the total areas which are outside the 'permanent' ice edge or 7/10 minimum limits are similarly displayed in Table II.

Figures 2 to 6 show the results of the calculations of the sea ice areas outside the 7/10 minimum limit for each month. Each graph shows the variations from year to year in the area of sea ice for each sector and for the whole hemisphere. Areas for the 'Pacific' sectors and therefore also for the hemisphere are limited

to the 6-year period 1969–74 for reasons already discussed; but areas for the winter months in the 'Atlantic' sectors are shown in Figures 2, 3 and 4 for the whole period 1966–74.

TABLE I—MEAN TOTAL AREAS WITH 7/10 (OR MORE) SEA ICE ($\times$ 10⁶ km²)

	February	March	April	August	September
Mean 1969–74	15·47	15·19	14·01	6·58	6·88
Mean 1969–71	15·69	15·21	14·23	6·85	7·00
Mean 1972–74	15·25	15·17	13·80	6·32	6·77
1972–74 mean as a percentage difference from 1969–71 mean	−3	−0·3	−3	−8	−3
Maximum value	15·87	15·59	14·68	7·44	7·42
Year	1970	1969	1969	1969	1969
Minimum value	14·52	14·53	13·48	5·74	6·23
Year	1974	1974	1974	1973	1971
Departure from 1969–74 mean (per cent)	+3 to −6	+3 to −4	+5 to −4	+13 to −13	+8 to −9

TABLE II—MEAN AREAS OUTSIDE 7/10 MINIMUM LIMITS ($\times$ 10⁶ km²)

	February	March	April	August	September
Mean 1969–74	2·17	1·97	1·78	2·18	1·73
Mean 1969–71	2·40	1·99	2·00	2·45	1·84
Mean 1972–74	1·95	1·95	1·57	1·92	1·63
1972–74 mean as a percentage difference from 1969–71 mean	−19	−2	−22	−22	−11
Maximum value	2·57	2·37	2·45	3·04	2·28
Year	1970	1969	1969	1969	1969
Minimum value	1·22	1·31	1·25	1·35	1·09
Year	1974	1974	1974	1973	1971
Departure from 1969–74 mean (per cent)	+18 to −44	+20 to −33	+38 to −30	+39 to −38	+31 to −37

Discussion. It can be seen from Table I that, in every month, the 1972–74 mean was less than the mean for the previous three years. In February, April and September the decrease over the whole Arctic region was 3 per cent; in March it was 0·3 per cent and in August it was 8 per cent. The departures from the 1969–74 means of the maximum and minimum monthly values, also shown, can be quite large varying from +5 to −6 per cent in winter and from +13 to −13 per cent in summer.

The monthly graphs, Figures 2–6, indicate the contributions from each sector towards the 'total' areas outside the 7/10 minimum limit. It can be seen that heavy or light ice years over this 'total' area were not due to large or small ice areas, respectively, in each region. On the contrary, the graphs indicate that heavy ice conditions in one region are often largely off-set by simultaneously light conditions elsewhere.

Of particular interest is the relationship, in winter, between ice conditions in the East Canadian sector and those in the Greenland and Barents Seas. In February, March, and to a lesser extent in April, there is an inverse relationship between these regions in that heavy ice conditions occur simultaneously over the Greenland and Barents Seas while light conditions prevail off eastern Canada, and vice versa.
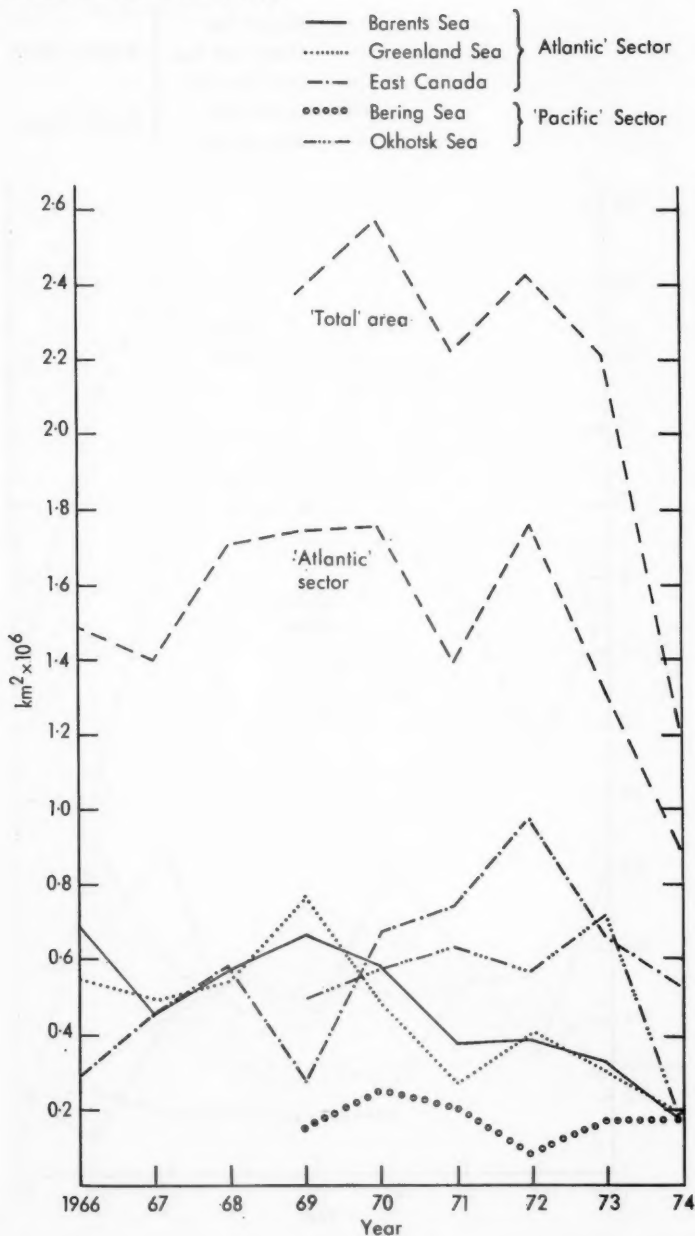
FIGURE 2—YEAR-TO-YEAR VARIATION OF AREAS OF SEA-ICE COVER IN FEBRUARY,
OUTSIDE MINIMUM LIMIT OF COVER FOR WHOLE PERIOD
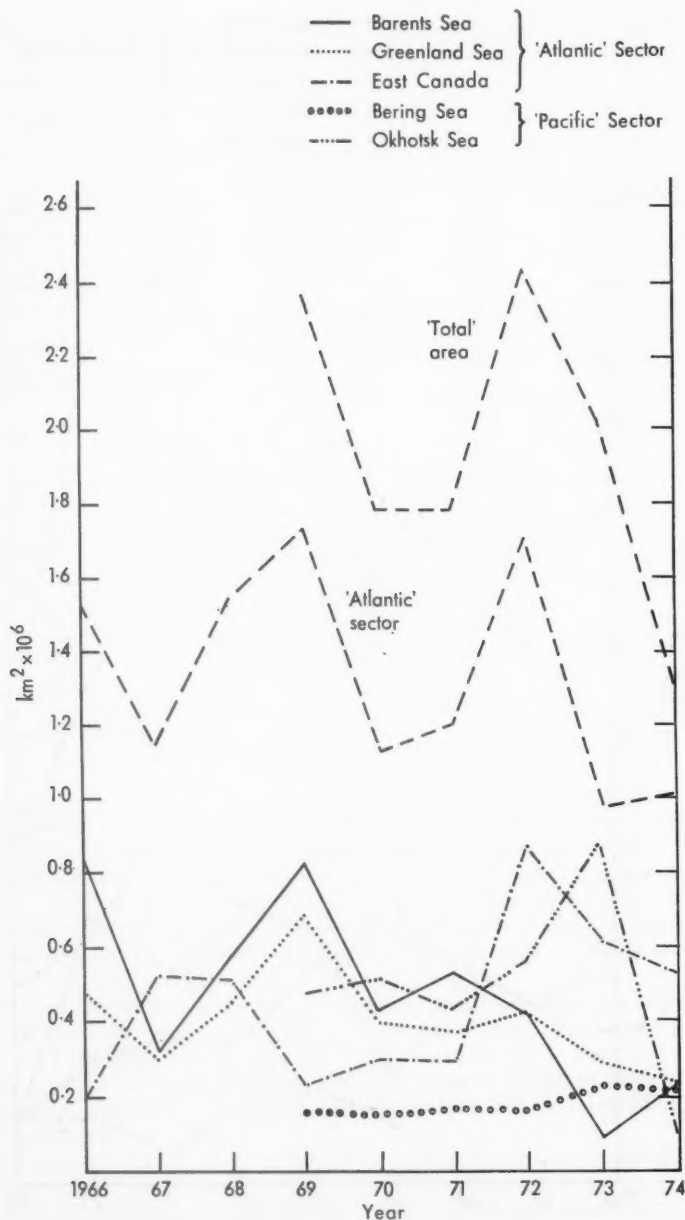'Cover' implies at least 7/10 cover of sea ice per 1° 'rectangle'.

FIGURE 3—YEAR-TO-YEAR VARIATION OF AREAS OF SEA-ICE COVER IN MARCH,
OUTSIDE MINIMUM LIMIT OF COVER FOR WHOLE PERIOD
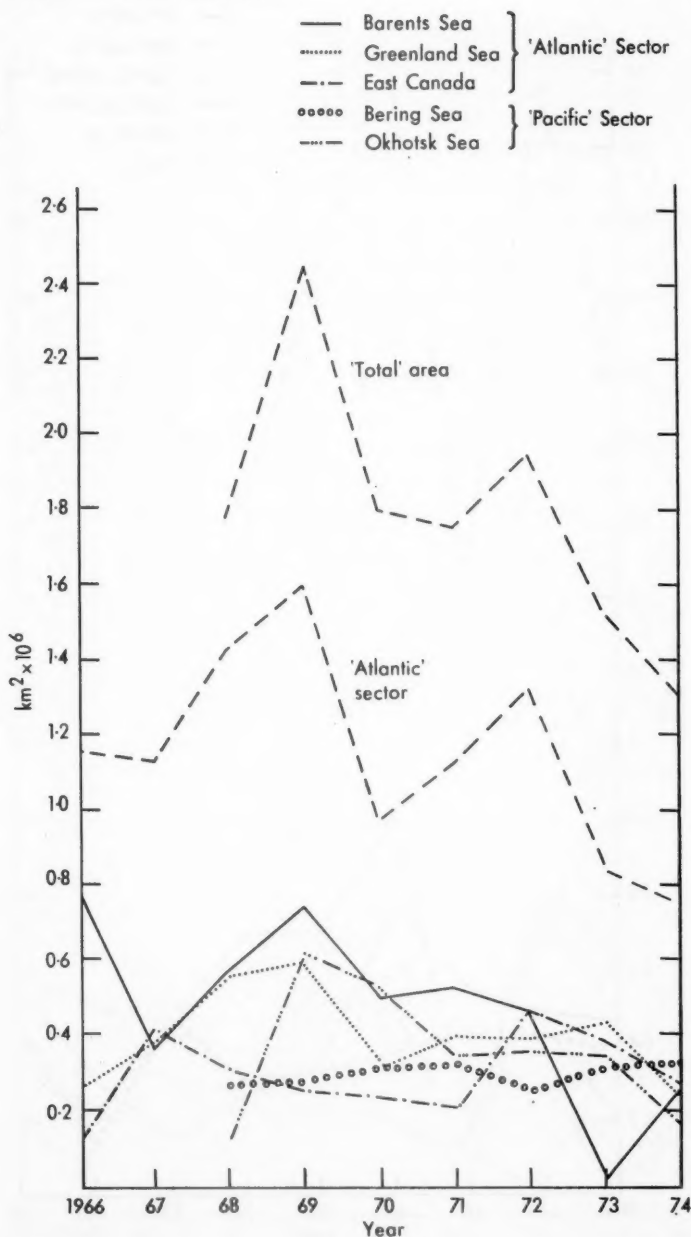See note under Figure 2.

FIGURE 4—YEAR-TO-YEAR VARIATION OF AREAS OF SEA-ICE COVER IN APRIL, OUT-
SIDE MINIMUM LIMIT OF COVER FOR WHOLE PERIOD
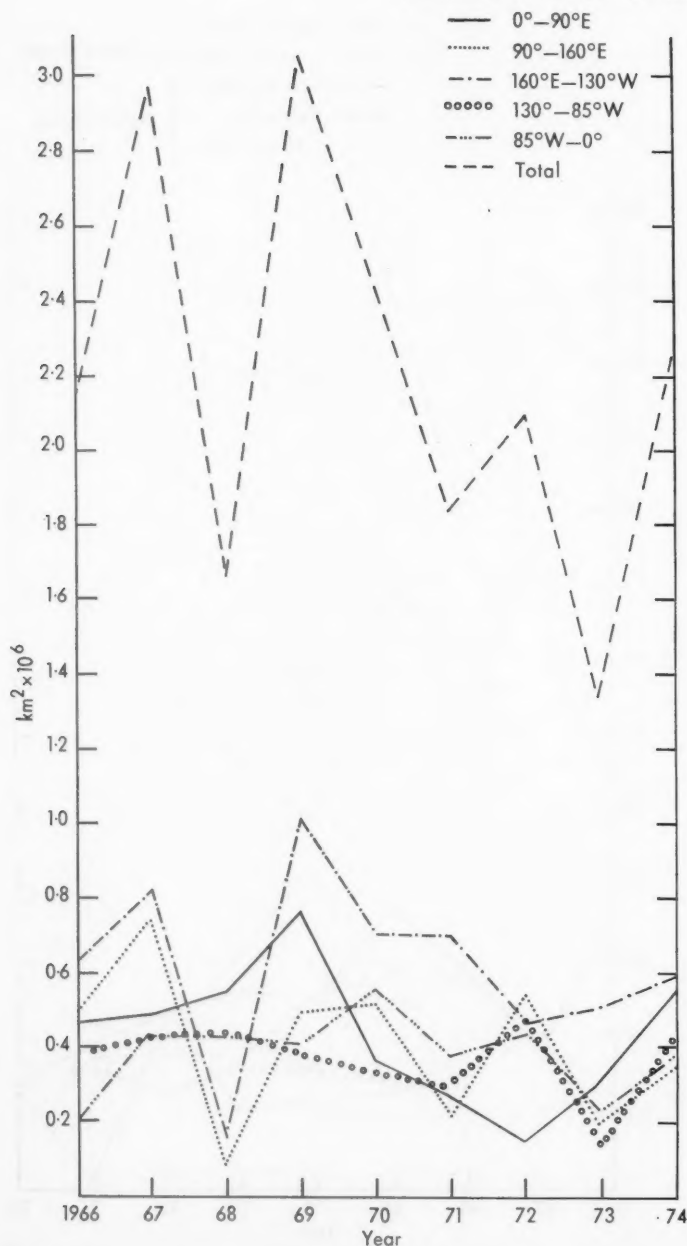See note under Figure 2.

FIGURE 5—YEAR-TO-YEAR VARIATION OF AREAS OF SEA-ICE COVER IN AUGUST,
OUTSIDE MINIMUM LIMIT OF COVER FOR WHOLE PERIOD
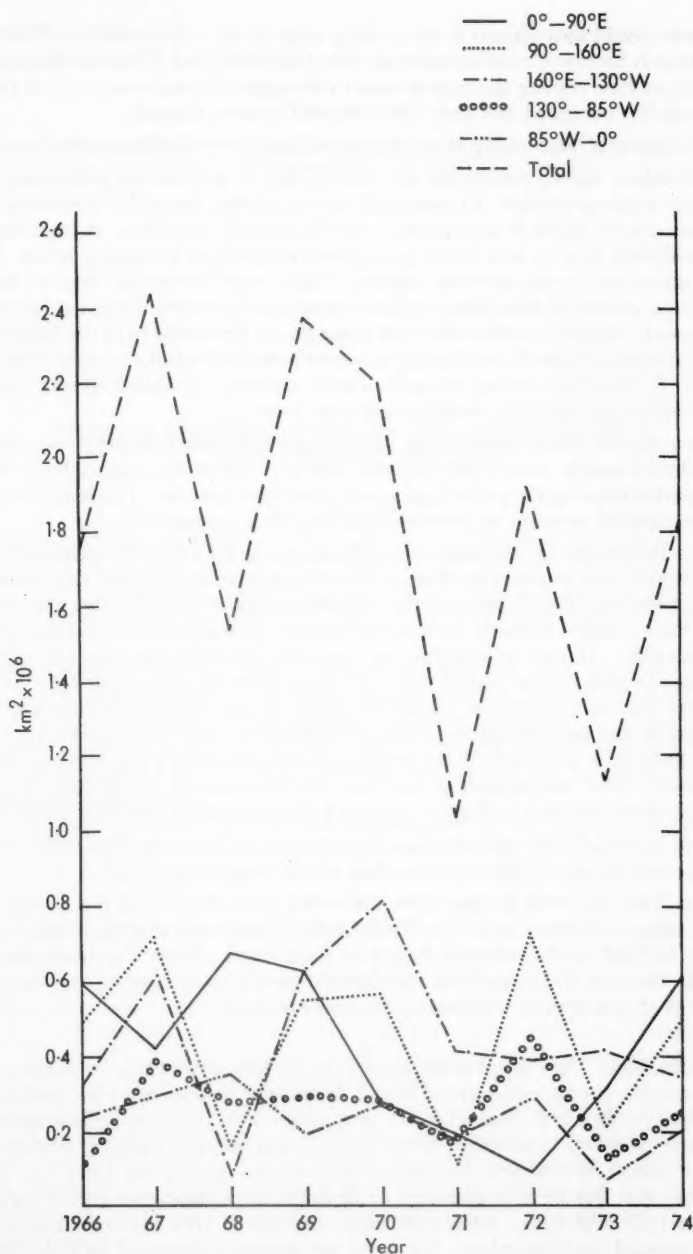See note under Figure 2.

FIGURE 6—YEAR-TO-YEAR VARIATION OF AREAS OF SEA-ICE COVER IN SEPTEMBER,
OUTSIDE MINIMUM LIMIT OF COVER FOR WHOLE PERIOD
See note under Figure 2.

There would also appear to be a fairly close direct relationship in February and March between conditions in the East Canadian and Okhotsk Sea sectors, though, at least during the period under investigation, maximum values in the Okhotsk Sea occurred one year later than off eastern Canada.

No consistent relationship between sectors is apparent in the summer months.

Anomalous sea-ice conditions are chiefly due to anomalous winds over the previous week or weeks.[2] In practically every region, heavy ice conditions are associated with winds from a north or north-westerly direction. A high degree of meridional flow at low levels is required to produce persistent winds from these directions in one or more regions. This would invariably lead to winds from some southerly direction in other regions which would in turn result there in unusually light ice conditions. For example, in February 1972 the large area of ice off eastern Canada resulted from a north-westerly wind anomaly over that region. In the same period a south-easterly anomaly prevailed off east Greenland resulting in light ice conditions in that sector.

The apparent direct relationship in February and March between conditions off eastern Canada and in the Okhotsk Sea may reflect the atmospheric long-wave pattern during the period 1969 to 1974 in these months. It is hoped to give a more detailed account of these relationships in a later article.

From the graphs for the winter months it can be seen that the general shape of the 'total' area curve is similar to the Atlantic sector curve for the common period 1969–74. This is because the Atlantic sector contributes twice as much as the Pacific sector towards the area beyond the 7/10 minimum limit in each of these months. It may reasonably be expected therefore that the percentage decreases in area for the period 1971–74 below those for the period 1967–70 for the total area will have been similar to those for the Atlantic sector. On this assumption the percentage decreases in total area from 1967–70 to 1971–74 would have been as follows: February 3 per cent, March 0·4 per cent and April 3 per cent. The corresponding decreases for the summer months are readily available from the data and were: August 9 per cent and September 9 per cent.

These figures clearly indicate that the percentage decreases from 1967–70 to 1971–74 are greater in the summer than in the winter months.

From Table I it can be seen that the mean area under 7/10 ice during the period 1969–74 is $15·47 \times 10^6$ km^2 in February (the month of greatest area) and $6·58 \times 10^6$ km^2 in August (the month of least area). Thus the mean annual range in the area of the northern hemisphere with 7/10 or more sea ice concentration is 57 per cent of the mean February amount.

Conclusion. Very large seasonal changes in the area of sea ice occur each year, and the changes in a given month from year to year are also sometimes considerable. But it is clear that the area under 7/10 ice cover, when meaned separately over two consecutive 3-year periods, has decreased slightly during the six-year period of complete hemispherical data coverage from 1969–74. It is suggested that this trend is also applicable to the two consecutive 4-year periods between 1967 and 1974. Extremely large changes in area may occur in some sectors around the hemisphere, but these are normally balanced by quite large changes in the opposite sense in other areas. The variability in the total area is usually less than 10 per cent.

REFERENCES

1. London, Meteorological Office. Monthly Ice Charts, London, HMSO, 1966–74.
2. SANDERSON, R. M.; Ice-edge movements in the Greenland Sea. *Mar Obsr, London*, **41**, 1971, pp. 173–183.

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HUMAN INTERVENTION IN THE OPERATIONAL OBJECTIVE ANALYSIS

By F. SINGLETON

Summary. The recent enlargement of the intervention team in the Central Forecasting Office is indicative of the importance attached to the concept of subjective control over the objective analysis process. The problems presented by the various forms of data are described with a brief summary of the objective analysis sequence. The techniques of intervention, future developments and explanation of what appears to be a contradiction in terms are discussed by a member of the team.

Introduction. In the *Concise Oxford Dictionary* the verb 'to intervene' is defined variously as 'come in as something extraneous, occur in the meantime; come between, interfere, so as to prevent or modify a result etc.' In the Central Forecasting Office (CFO) the word is used to describe subjective modifications to the data used by the objective analysis programs as part of the numerical-forecast program suite.

The need for intervention is occasioned primarily by the problems of developing objective analysis techniques to cope satisfactorily with the large areas of sparse data that exist over the Atlantic and Pacific Oceans. For the purposes of numerical forecasting the CFO analysis area covers most of the northern hemisphere. Errors in numerical forecasting are often attributable in part at least to deficiencies in the analyses. The aim of the intervention team in CFO is to improve analyses to such a state that forecast errors might be assumed to be due solely to the formulation of the forecast programs or limitations in the basic concept of numerical forecasting. The consistent production of good analyses is an essential first step not only to good forecasting but also to the eventual elimination of defects in the forecast programs.

This note describes the use by CFO of subjective techniques to aid the production of good objective analyses. The theory and practice of the subjective modification and interpretation of the output from numerical-forecast programs have been discussed in a recent paper by Kirk.* These two papers, together, describe the complementary roles of human being and computer in the production of forecast charts.

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* KIRK, T. H.; The use of numerical forecasts. *Met Mag, London*, **103**, 1974, pp. 14–20.

The data

Conventional synoptic data. Over North America and Eurasia the quantity of data available is such that the objective analysis program can produce an optimum fit with greater consistency than can a human being. Over these areas the objective analysis is occasionally better and rarely worse than that made by an experienced human analyst. The computer is better at making systematic corrections to random instrumental error as well as allowing for systematic differences between various types of radiosonde equipment and varying practices in applying solar-radiation corrections.

Problems of analysis are somewhat greater over less well-populated land masses, those of North Africa and Arabia for instance, where the sparsity of data is such that random errors are more difficult to eliminate. However, small details in such areas are not generally essential to the production of numerical forecasts in higher latitudes. It is usually sufficient to maintain only a general level of pressure-contour heights.

Oceanic areas present the principal problems to both human and objective systems in that precise analysis in these areas is frequently of critical importance to the numerical forecast. Surface reports have marked diurnal variations in quantity because many ships carry only one radio operator. The distribution of data is also subject to annual variation due to the seasonal variability of routes taken by shipping. Difficulties in radio reception and inevitable errors both in transmission and reception of morse numerals cause the general quality of ship observations to be lower than that from land stations. Since the withdrawal of United States weather ships there have been large areas of ocean with no conventional upper-air data. Even areas where ship and island radiosonde data are received present similar problems to those from the sparsely occupied land areas—namely the detection of random instrumental errors and transmission errors.

Aircraft reports. These have long been used by forecasters as a valuable source of data supplementing conventional observations. Like ship reports there are, however, marked diurnal variations in the quantity of data owing to restrictions imposed by governments upon times of take-off and landing. The majority of aircraft winds are, in fact, not applicable to the main synoptic analysis times of 0000 and 1200 GMT. Although most aircraft reports are of high quality there are some occasions when the reported wind received at Bracknell is not consistent with that which might be expected at the reporting position. This is particularly evident when the aircraft has passed through a marked trough or ridge but there are other occasions when such errors are less easily detectable. Other errors can occur through distorted radio-telephony reception. Instantaneous winds measured by modern navigational equipment, although accurate, may, nevertheless, be unrepresentative of the large-scale flow. The main problem posed by aircraft winds, however, is that the winds whilst implying gradients of pressure-contour height do not give contour heights with which to associate the gradient. Some years ago aircraft reports used to contain a D-factor, the difference between pressure altitude and true height, from which a pressure-contour height could be deduced. The installation of radar altimeters in contemporary aircraft and the re-introduction of the D-factor would make a valuable addition to aircraft reports.

Satellite wind reports. These wind measurements are obtained by tracking cloud movements on pictures transmitted from the geostationary satellites

(GOES) situated over the equator. Experience in CFO has shown these to be very high-quality data and, being measurements over 20 minutes or so, very representative. Like aircraft winds, however, they only give gradients of contour height. Over the Atlantic these winds are available in areas where there is some cloud over an arc from about 45° north of the sub-satellite point (over the coast of Brazil) to the coast of West Africa. The main use of the satellite winds is the delineation of flow patterns at upper levels in areas where there are few aircraft.

SIRS. Satellite infra-red temperature soundings have, so far, proved to be among the least satisfactory of all the information used by the analyst. Heights of pressure levels deduced from these soundings are subject to large random errors in high latitudes while in low latitudes they were for several months generally too high, from 10 to 20 dam at 100 mb. Satellite temperature soundings are, probably, the most potentially valuable of all satellite data to the numerical forecast and this makes their lack of reliability to date all the more disappointing.

Satellite cloud pictures. These data are of great value to the human analyst as an aid to positioning surface frontal features, upper troughs, ridges, vortices and, sometimes, jet streams. By comparing visual and infra-red pictures the analyst can deduce the vertical and horizontal extent of cloud as an aid to the analysis of humidity fields.

The operational objective analysis. The first stage in the analysis sequence is the production of a background field or first-guess analysis. This is, in effect, a 12-hour forecast based on data from the last main synoptic hour over most of the octagon area but on persistence near the boundary. In areas where data are dense the analysis is determined almost exclusively by the new data; where data are non-existent the background becomes the analysis and in areas of sparse data the analysis is a mixture of background and data. This is analogous to the techniques of manual analysis where the analyst uses history from his last two or three charts and in areas of little data draws what is in effect a short-period forecast.

As data are received at Bracknell they are subjected to various quality-control programs. The communications computer lists for correction all messages with invalid indicators, addresses etc. The synoptic data bank (SDB) program tests for pressure–tendency consistencies, ship movements, correct date and time, hydrostatic consistency, temperature–dew-point consistency etc. Following these checks messages will be rejected in whole or in part or, in some cases, corrected. The accepted data form the Basic Analysis Data Sets (BADS) with rejected data remaining in the SDB as flagged data. During the operational analysis sequence CFO receives a full list of all data in the BADS as well as a list of flagged data with reasons for flagging.

The objective analysis fits a polynomial of high degree to the data contained in the BADS and the background field over the whole of the analysis area. The sequence of events is as follows:

(a) Analysis at 1000 mb—this provides a base for conversion of SIRS thickness values to contour heights.

(b) Analysis at 100 mb. The difference between analysed and observed heights is used to provide corrections to reported contour heights down to 500 mb as a technique for eliminating random errors between radiosondes, all values having previously been corrected for systematic instrumental differences.

(c) Analysis at 500 and 300 mb.

(d) The differences between background and analysis fields at the four levels so far analysed are used to modify background fields at the other analysis levels 200, 400, 700 and 850 mb. This is to obtain a certain amount of vertical consistency.

(e) These latter four levels are now analysed.

(f) Coefficients of the polynomials at the eight levels are now fitted three-dimensionally to give greater vertical consistency and to allow extraction of the fields at 900, 800 and 600 mb. (The forecast program uses for computation the analysis fields at 1000, 900, 800, 700, 600, 500, 400, 300, 200 and 100 mb.)

In current practice each level is analysed in three scans; the first uses heights only, the second uses heights and winds (if reported together), and the third uses all heights and winds. Data failing certain fitting tests will be rejected after each scan but will be tested again after the next scan. Weightings given to the data and the background vary with the density of data and the type of observation.

In order to produce a forecast to a schedule any forecaster, whether human being or computer, has to have a cut-off time by which analyses have to be begun regardless of what data may or may not have been received. Subsequently, 'retard' data for that analysis time will lead to an updating of the analysis. The computer uses this updated analysis as a basis for the background field for the next main hour. One important difference between the computer and the human is that the former uses data only at 0000 and 1200 GMT (plus or minus 3 hours for aircraft and satellite data) whereas the latter uses all the intermediate data. The possible introduction of a four-dimensional analysis system may rectify this in the future.

Intervention times. The latest times at which information can be fed into the computer at the various stages described above are 0230 or 1430 GMT for the fine-mesh rainfall (rectangle area) forecast, 0315 or 1515 GMT for the hemispheric coarse-mesh (octagon area) forecast and 1100 or 2300 GMT for the update analysis. Action to modify data before the first two of these times is known as pre-emptive intervention since the aim is to forestall or pre-empt problems that may cause poor analyses. Intervention before 1100 or 2300 GMT is usually done to correct known errors in the analysis obtained at the operational cut-off time but may also be used to pre-empt the effects of known retard data.

Intervention types. There are three types of intervention in use in CFO as follows:

Correction. There are two forms of correction procedure. The first is to combat errors in message format or corruptions in reception of messages, the second is to deal with random errors at isolated stations. For the first, messages from certain key stations are carefully scrutinized for errors beyond the capability of the data-bank quality-control programs to correct. From supplementary information such as a Part B of upper-air messages or inspection of other levels it may be possible to deduce correct messages. The corrected message is then broadcast for the benefit of other recipients as well as the synoptic data bank. The deduction of random errors may depend upon a number of factors, known developments, cloud pictures, continuity, intermediate data, preliminary manual analyses etc. The assessment of such errors will inevitably be subjective and,

particularly at the pre-emptive stage, may be in error. Correction of random errors is, therefore, effected by a message direct to the computer for use by the BADS. Corrections at the pre-emptive stage for the fine-mesh forecast may be amended before the main forecast and again, if necessary, for the update analysis.

Rejection. In areas where there are moderate quantities of data and an incorrect value may cause problems to the analysis program, rejection may be more appropriate than correction. Rejection may be used if an observation is known to be incorrect but there is doubt at the time what is the correct value. Rejection at this pre-emptive stage may be reversed later.

Bogusing. Where there is a sparsity of data at the analysis time but where, perhaps, using intermediate data, satellite pictures or other information the analyst is in a position to improve upon the background field at the pre-emptive stage or the operational analysis at the update stage then he may invent observations to ensure that the objective analysis is consistent with these other data. Bogus data inserted at the pre-emptive stage can be amended or deleted at the update stage.

Difference in emphasis—pre-emptive to update intervention. Before the operational forecast cut-off time the intervention team looks for possible errors in the background field that will not be counteracted by new data so that bogusing action can be taken. Otherwise the main intervention effort concerns the detection of message errors and random errors at key stations to deal with which the main tools are correction and rejection.

The timings of satellite orbits are such that pictures can be studied across most of the Atlantic area before the operational cut-off time and, on the basis of the information obtained, pre-emptive action taken on humidity, using bogusing techniques.

Between the operational and update stages charts are analysed manually in CFO at the surface, 500, 300 and 100 mb over the American–Atlantic–European sector of the hemisphere on the scale 1:20 million and over the whole hemisphere on the scale 1:30 million. Differences between manual and computer analyses are studied and reasons for differences investigated. Data received since the last cut-off are also examined and their probable effects on the update analyses assessed. Similarly, data for later times are studied for consistency with the analysis. Correction or rejection procedures may be applied to any data whether received before or after the operational cut-off. The main procedure likely to be employed at this time, however, is the addition of bogus data in areas where the objective analyses are considered to be in error.

With the exception of messages corrected, for format or corruptions, and fed to the data bank via the communication centre all intervention messages are read by the computer using punched cards. Intervention at the four levels surface, 500, 300 and 100 mb influences the remaining four analysis levels through the objective analysis scheme.

Possible future developments

Changes to schedules. The times by which forecasts are required by users are not always compatible with the production of the forecasts. Facsimile broadcast schedules and the requirements of civil aviation result in the operational analysis being used by the forecast suite before it can be vetted by CFO.

Despite the efforts of the intervention team the analysis will inevitably contain some features that may or may not be critical to a 24-hour forecast but are likely to lead to deterioration in longer-period forecasts. Within CFO itself, however, the times of output of 24-hour surface prognoses and synoptic reviews are such that the 36-hour forecast based upon 0000 or 1200 GMT is used as a basis for the 1200 or 0000 GMT 24-hour surface prognoses.

For CFO purposes it is intended within the near future to shorten the operational forecast to cope solely with the short-term requirements but to extend the update forecast to 84 hours. This will result in some improvement in the 36-hour guidance for the senior forecaster and may also give better guidance to the medium-range forecaster although here the effect of using a forecast based upon a superior analysis may be negated by having to use an 84-hour forecast instead of one for 72 hours for the day 3 guidance.

For the short-period forecasts some benefit would probably accrue if the user could wait a further 30 minutes to allow time for inspection and possible modification of the analysis by the intervention team.

Use of visual display units. Owing to delays in punching and verification of cards for intervention input the cut-off is approximately 30 minutes before the start of the forecast suite. By use of a VDU and keyboard in CFO it is possible for the intervention team to submit messages direct to the computer for use by the BADS and so reduce the time between the intervention dead-line and the analysis program. This type of intervention is still indirect in that data are inserted in the hope that they will produce a required effect. Techniques are being developed, however, for use in CFO by which contour lines might be redrawn directly on to a VDU. At present this method is available to modify the background field only but could possibly be extended to modify the operational analyses at a later date.

Intervention procedures using a VDU and keyboard to insert data and the background modification techniques are available to CFO on an operational basis but are still subject to further development. Their use is supplementary to the established punched card intervention methods and rather in the nature of field trials. It is probable that, in time, punched-card intervention will become a back-up procedure for the more sophisticated and faster VDU techniques.

Monitoring of the data bank. At present the synoptic data bank is filled at discrete intervals but there is only one print-out (after the start of the operational analysis) of data, both accepted and flagged. Some data contain errors that escape detection by CFO and some arrive too late for vetting. In order to make maximum use of all available data it will be necessary to have a continuous flow of data from the communication centre to the computer, with CFO being able to interrogate the data bank at any time for lists of data, accepted or flagged. Such information would be received in CFO on a VDU, printed, if necessary, on a thermal printer and corrections made by means of the VDU and keyboard.

Such monitoring would also enable CFO to know what data are in the data bank at the scheduled start of the forecast suite and to decide whether it would be worth a short delay to await the arrival of more information. It may even be desirable for control of all the operational programs—analysis, plotting, forecast—to be on command from the keyboard in CFO.
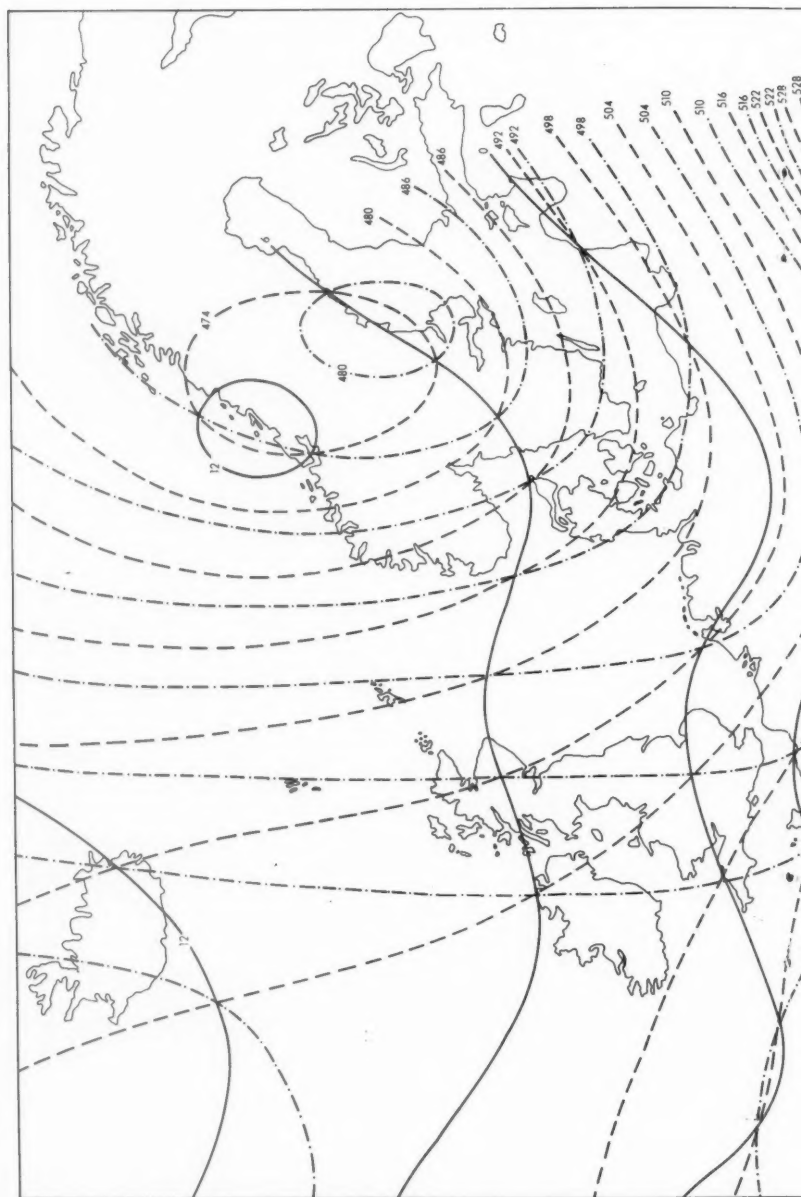
Satellite data. Humidity intervention might be possible in the future by using digitized satellite cloud data for direct input to the analysis program. Similarly

Photograph by C. J. Richards

PLATE I—HEAT THUNDERSTORM AFTER A FINE HOT DAY

The photograph was taken near High Wycombe, Bucks, at 1930 BST on 9 June 1970. Vigorous convection is evident within the cloud mass, with a recently formed anvil canopy spreading out from the cloud top.
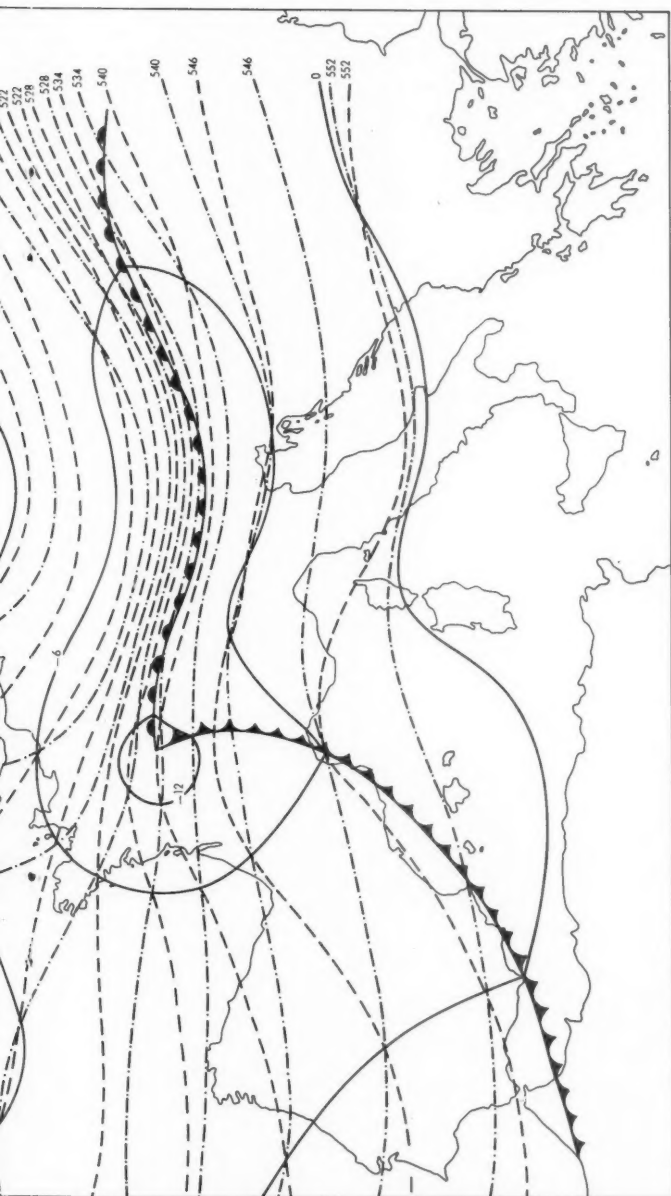
PLATE II—THREE-DIMENSIONAL SYNOPTIC WEATHER MAP FOR 28 DECEMBER
1783 AT 14 h

———— 1000-mb contours   – – – – 1000–500-mb thickness lines
–·–·– 500-mb contours
Heights are in decametres.

Photograph by M. M. Rathore

PLATE III—PHOTOGRAPH OF LIGHTNING TAKEN AT BRACKNELL AT MIDNIGHT ON 8 AUGUST 1975, LOOKING EASTWARDS

satellite radiation data contain some information about total precipitable water
and this, too, may be of use to the analysis program.

Improved manual analyses. Work is in progress with the object of using computer
plotting techniques to give CFO extra data not at present available in plotted
form. The two most important of these are charts on scales 1:10 and 1:15
million for the Atlantic and Pacific areas respectively to enable all ship reports
received to be plotted on station even if this means using an abbreviated form of
the report. Similar charts are also planned for analysis of aircraft and satellite
wind reports, particularly for the intermediate times of 0600 and 1800 GMT.
The intention is to try to obtain greater detail at the levels of greatest importance
to the numerical forecast with particular reference to detail appropriate to the
fine-mesh forecasts.

Feedback of information from CFO to programmers. The enlargement of the
intervention team has had the immediate and beneficial effect of increasing the
interchange of ideas between CFO and programming staff leading to steady
improvements in the quality-control and analysis programs. As a consequence
programmers are or soon will be investigating variations in techniques for using
SIRS data, different weightings of data, methods of humidity intervention and
improvements to quality-control techniques.

The philosophy of intervention. The need for human intervention in the
increasingly automated processes surrounding quality control and analysis
requires consideration both in practical and philosophical terms. On individual
occasions the need for either update or pre-emptive intervention can clearly be
demonstrated. However, there are occasions, at the pre-emptive stage especially,
when transcription errors or errors of judgement occur, leading to worse
analyses than would have otherwise occurred. It will be necessary to demonstrate
unequivocally the effectiveness of both update and operational intervention
probably by repeating in parallel the analysis programs without any inter-
vention at all and with intervention only at the update stage. Improvement in
the analysis techniques will gradually reduce the need for intervention and,
probably, the evaluation programs mentioned above should be repeated
periodically.

Experience of running forecasts without update analyses, when standby
computer facilities are used, suggests that such exercises will indicate a continu-
ing need for intervention. Should this state of affairs be accepted as a future
necessity or should effort be concentrated on trying to program the human
thought processes that constitute intervention? Such programs would undoub-
tedly be very unwieldy with some very complex logic and their development
would be an extremely costly process in man-hours alone. The human analyst
being able to study selectively data from all the various complex sources can
build up an analysis piecemeal perhaps with the option of more than one possible
solution until the arrival of a small amount of new data—one ship report, one
satellite picture possibly—clarifies the position. In short the human analyst
can employ judgement and experience and is able to exercise logic of a quality
unlikely to be programmed in the foreseeable future.

Even if it were deemed worth while to attempt to program the functions of
the intervention team the development of the programs would probably be over-
taken by technological developments in the instrumental field such as improved
satellite sensing techniques, remote-reading stations, the use of contant-level

balloons etc. It is suggested therefore that, although intervention methods will change, the need for intervention as an integral part of the operational objective analysis scheme, an apparent contradiction in terms, should be allowed for in any planning concerning CFO.

A SPRING SINGULARITY IN GLOBAL RADIATION BENEATH OVERCAST SKIES IN THE CANADIAN PRAIRIES

By A. J. W. CATCHPOLE
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Summary. A study of seasonal variations in hourly global radiation beneath overcast skies detects an abrupt decline in its intensity in spring. This is attributed to changes in the multiple reflection of solar radiation between ground and sky.

Introduction. Inhabitants of the Canadian Prairies are familiar with a variety of optical effects which develop when cloud sheets form over snow-covered ground.[1] These optical effects are caused by the high reflectivities of fresh snow and cloud. When cloud is superimposed over snow there may be considerable multiple reflection of solar radiation between the sky and the ground, and the general effects of this are to cause a strong upward flux of solar radiation and to augment the downward flux with multiply reflected radiation. On rare occasions the intensity of the upward flux is almost as great as that of the downward and this causes the optical effect of white-out in which the visual perception of distance, size and location of objects is distorted. When the snow cover is broken by dark patches of water or bare earth, multiple reflection may selectively illuminate the base of the cloud so that an image of the ground is seen in the cloud. This phenomenon has been termed iceblink, cloud map or water sky in the Arctic where it is commonest. In the prairies multiple reflection is rarely manifest in such striking optical effects as white-out and iceblink, but it commonly augments the intensity of solar radiation beneath overcast days in winter. Indeed, this paper shows that the average hourly intensity of global radiation on overcast days at Winnipeg is greater in late winter than in midsummer.

The purposes of this paper are to compare seasonal variations of global radiation intensity at Winnipeg beneath clear and overcast skies and to focus attention upon an abrupt decline in the intensity beneath overcast skies in spring. This decline accompanies the spring thaw and is presumed to arise from a decrease in multiple reflection.

Multiple reflection. The process whereby solar radiation is reflected back and forth between the ground and the sky was first termed multiple reflection by Ångström and Tryselius.[2] Deirmendjian and Sekera[3] used the term multiple scattering, and Möller[4] used the term backscatter to denote the part of global radiation that is contributed by multiple reflection. The amount of multiple

reflection is apparent in the difference between actual global radiation G and the global radiation G_0 which would obtain over a perfectly black surface. The ratio between these G/G_0 is termed the intensification ratio. The magnitude of the intensification ratio depends upon the albedo of the ground a, and the reflectivity of the sky d. The actual global radiation can be treated as the sum of G_0 and an infinite series of reflected radiation terms:

$G = G_0 + G_0\,a\,d + G_0\,a^2\,d^2 + G_0\,a^3\,d^3 + \ldots$

This is a convergent series the limit of which is given by $(1 - ad)^{-1}$. Thus, Ångström and Tryselius showed that:

$$\frac{G}{G_0} = (1 - ad)^{-1}$$

and concluded that at Abisko (68°21′N, 18°49′E) the intensification ratio typically ranges from highest values of 2·1 with overcast skies in winter, to lowest values of 1·02 with clear skies in summer.[2] Möller derived intensification ratios of 1·14 – 1·19 beneath overcast skies at Toronto, and of 1·46–1·60 beneath overcast skies at Moosonee in northern Ontario, Canada.[4] Sawchuk calculated mean daily intensification ratios at Toronto between 1 January and 30 June 1970 and found that, with snow-covered ground, the ratio is usually between 1·5 and 3·0, and that, with snow-free ground, it is usually between 1·2 and 1·3.[5] Thus, under favourable circumstances, multiple reflection may sustain an actual global radiation which is two to three times greater than that which would obtain over a perfectly black surface.

The process of multiple reflection has attracted the attention of climatologists endeavouring to estimate global radiation receipt from measured sunshine duration using linear regression equations of the form:

$\dfrac{G}{G_a} = a' + b\,\dfrac{n}{N}$ where G = actual global radiation,

$\qquad\qquad\qquad G_a$ = intensity of solar radiation on a horizontal surface at the top of the atmosphere,

$\qquad\qquad\qquad n$ = actual duration of bright sunshine,

$\qquad\qquad\qquad N$ = maximum possible duration of bright sunshine.

It seems that multiple reflection enhances G to such an extent in winter that pronounced seasonal variations in the coefficients a' and b are generated. This problem has been examined by Mateer,[6] Bennett,[7] and by Driedger and Catchpole.[8]

Data and method. The data described in this paper were observed at Winnipeg International Airport, a synoptic meteorological station operated by the Canadian Atmospheric Environment Service. The analysis examines hourly global radiation (direct plus diffuse solar radiation on a horizontal surface) observed by an Eppley 180° pyrheliometer between January 1961 and December 1965. Since a purpose of the analysis is to classify radiation according to sky conditions, hourly durations of bright sunshine, observed by a Campbell–Stokes sunshine recorder, are also used. A total of 21 900 pairs of hourly observations of global radiation and sunshine duration are analysed in this research. Throughout this paper time is given in Local Apparent Time (LAT).

The main purposes of the paper are to describe seasonal variations in global radiation beneath overcast skies in both absolute and relative terms. Overcast skies are arbitrarily defined as occasions when the duration of bright sunshine in a particular hour is equal to, or less than, 1/10 hour. Likewise, clear skies are arbitrarily defined as occasions when the duration of bright sunshine is equal to, or more than, 9/10 hour.

At the outset it was expected that the amount of multiple reflection might vary with time of day in response to diurnal variations in zenith angle and state of snow surfaces. Therefore, no attempt was made to amalgamate hourly data into daily totals, and the seasonal regimes of radiation observed at particular times of day were examined.

However, it was also expected that a period of only five years would be too brief for purposes of calculating mean hourly global radiation on each day. Consequently, the year has been divided into overlapping pentads to allow means to be calculated from larger samples than would otherwise have been the case. The first pentad is 1–5 January, the second 2–6 January and the third 3–7 January. This use of overlapping pentads has a smoothing effect upon the data illustrated in Figures 1 and 2.

In the first part of the analysis the 25 hourly observations of global radiation in each pentad are classified according to whether or not they were observed beneath clear or overcast skies. Pentad means of overcast and clear sky global radiation are then calculated for each hour.

In the second part, the mean global radiations with overcast skies are expressed as percentages of the maximum global radiations observed in the corresponding time intervals. The first part of the analysis examines absolute variations in global radiation beneath overcast skies and the second part examines relative variations.

Results. The voluminous nature of the results militates against their being presented in their entirety. Figure 1 contains seasonal variations of mean global radiation beneath clear and overcast skies for three hours, namely, 10–11, 11–12 and 12–13 LAT. Figure 2 contains mean global radiations expressed as percentages of the corresponding maxima. In this case the hours selected for exemplification are 09–10, 12–13 and 15–16 LAT. Figure 1 demonstrates that the seasonal regimes of global radiation beneath overcast skies are quite different from those beneath clear skies. The latter display the wide amplitude between a summer maximum and a winter minimum expected of a station located at 50° N. Before the middle of March the seasonal regimes of global radiation beneath overcast skies roughly parallel those beneath clear skies. However, in late March and early April there is a sharp decline in the mean intensity of global radiation beneath overcast skies. Throughout summer this mean intensity varies irregularly but, in general, values remain similar to those which obtain in February.

The hours selected for examination in Figure 1 are those occurring in the middle part of the day when absolute radiation intensities are greatest. Early morning or late afternoon hours are less suitable for illustrating seasonal regimes since they are nocturnal near the winter solstice. However, the results of this analysis show that this spring singularity is also apparent in the morning and afternoon. To illustrate this point Figure 2 contains data observed at widely separated intervals during the day.
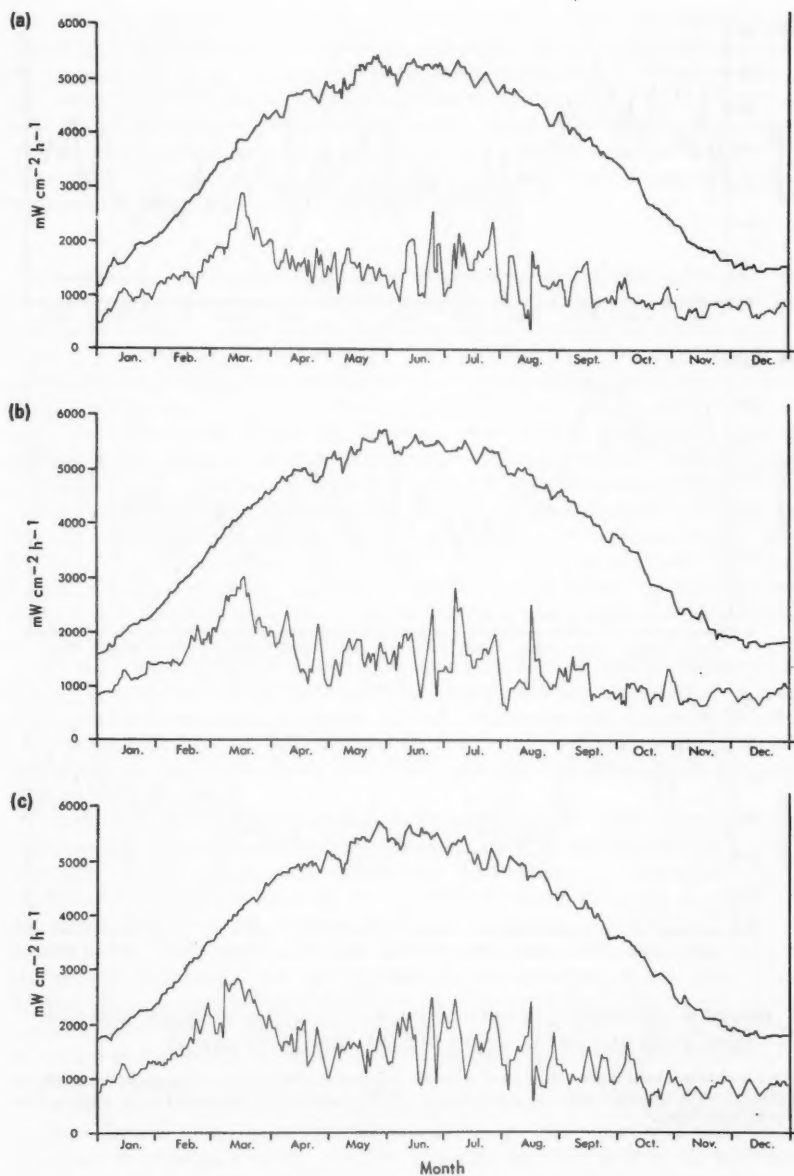
FIGURE I—MEAN GLOBAL RADIATION AT 10–11 LAT (a), 11–12 LAT (b),
AND 12–13 LAT (c) AT WINNIPEG, JANUARY 1961–DECEMBER 1965

The means are calculated in overlapping pentads and, in each graph, the upper curve refers
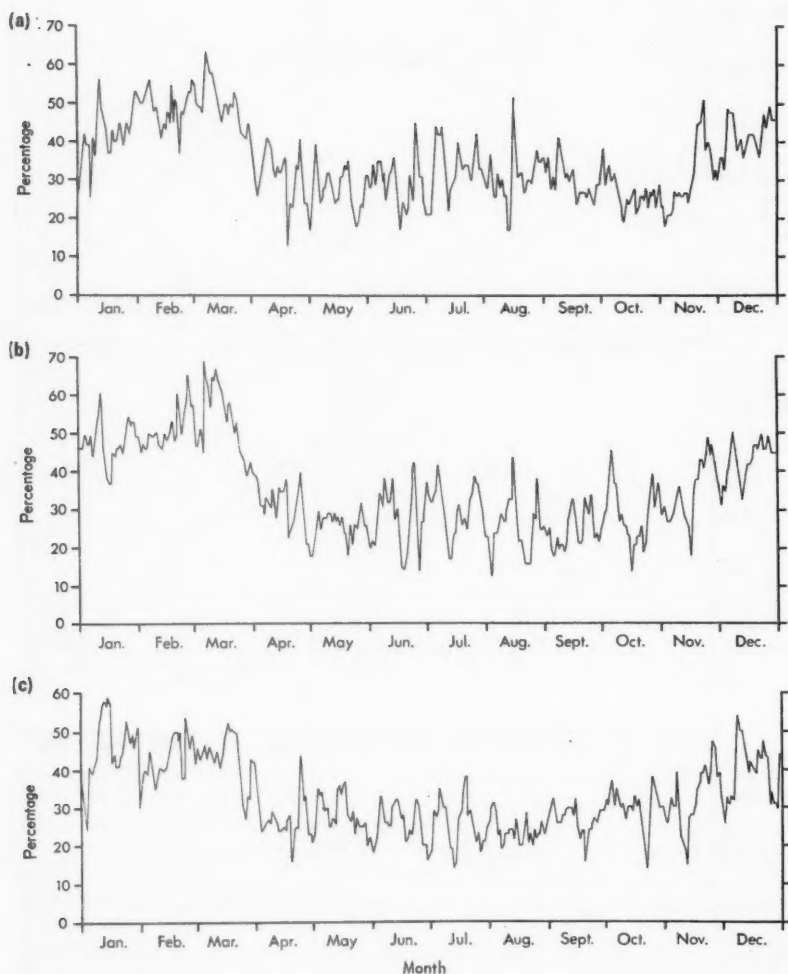to clear skies and the lower curve to overcast skies.

FIGURE 2—RELATIVE INTENSITY OF GLOBAL RADIATION BENEATH OVERCAST
SKIES AT 09–10 LAT (a), 12–13 LAT (b), AND 15–16 LAT (c)

The relative intensities are calculated in overlapping pentads by expressing each mean global
radiation with overcast skies as a percentage of the maximum observed in the appropriate
pentad and hour.

Attention is first directed to Figure 2(b) since this is based upon the data in Figure 1(c). From November to February the global radiation beneath overcast skies is generally 40–50 per cent of the maxima observed in the corresponding time periods. In March this percentage rises to 50–70 per cent. Following a steep decline in the percentage in late March, values of 15–40 per cent persist until November when they rise to 40–50 per cent. Similar seasonal regimes are observed in Figures 2(a) and 2(c) but the spring singularity is somewhat less prominent in the earlier and later parts of the day.

Discussion. The outstanding feature detected by this analysis is the abrupt decline in absolute and relative amounts of global radiation beneath overcast skies in late March. This period of decline coincides roughly with the spring thaw of the snow cover at Winnipeg from 1961–65. Unfortunately, albedo is not measured at Winnipeg International Airport but the general features of the albedo change can be inferred from daily observations of snow depth. Kung *et alii* have shown that when the depth of snow exceeds 12·5 cm (5 inches) surface albedo remains high and does not vary with snow depth.[9] When depths fall below 12·5 cm albedo declines and is directly related to snow depth.

During 1961–65 the median date on which the snow thickness declined to 12·5 cm was 30 March and the earliest and latest dates were 20 March and 6 April. The interval spanned by these dates coincides precisely with the period of decline in global radiation beneath overcast skies. In 1961–65 the median date on which snow was reduced to a trace was 7 April and the earliest and latest dates were 25 March and 19 April.

Although there is good circumstantial evidence that the spring singularity is caused by a decline in multiple reflection engineered by the spring thaw, this must remain a tentative conclusion. Hourly measurements of ground albedo are required to confirm this conclusion and hourly measurements of cloud parameters are required to show that this singularity is not caused by a seasonal change in cloud opacity.

Another feature of the seasonal regimes worthy of discussion is the absence in Figure 1 of an early winter singularity comparable to that observed in spring. It might be expected that the snow-cover development in November would modify global radiation beneath overcast skies in much the same way as does the spring thaw, but the regimes in Figure 1 contain no evidence of such a modification. Perhaps this contrast between the period of snow development and that of thaw arises from the fact that the former occurs close to the winter solstice when absolute values of radiation are low while the latter occurs at the equinox when global radiation is stronger. It is significant that the analysis of relative radiation intensities in Figure 2 does detect a rise to higher percentages in early winter.

An additional noteworthy feature of Figure 1 is that the global radiation on overcast days is much more variable than that on clear days and that this is especially the case in summer. In part this may be attributed to the fact that the Campbell–Stokes sunshine record gives a very restricted picture of cloud conditions. It cannot distinguish between clouds differing in form, density or elevation. Undoubtedly the radiation received on overcast days will vary as these parameters vary. However, a statistical explanation may account for part of the variability of global radiation beneath overcast skies. Thus, clear

skies are generally more common than overcast skies at Winnipeg and the latter are particularly rare in summer. This is illustrated in Table I using the sunshine durations observed between 12 and 13 LAT.

TABLE I—MONTHLY PERCENTAGE FREQUENCIES OF OVERCAST AND CLEAR SKIES BETWEEN 12 AND 13 LAT AT WINNIPEG, JANUARY 1961–DECEMBER 1965

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Overcast	37	31	27	31	30	18	17	14	31	25	50	47
Clear	44	53	56	54	53	59	63	66	56	62	33	44

The percentage frequency of each type of sky determines the number of cases which have been used to calculate mean global radiation in Figure 1. A percentage of 100 would indicate that all 25 cases in a pentad fall into a particular category. Only 14 per cent of August skies are overcast from 12 to 13 LAT. This indicates that each of the mean global radiations with overcast skies during August in Figure 1(c) is calculated from an average of only 3·5 values. The greatest variability in Figure 1 is shown by the curves of global radiation beneath overcast skies in June, July and August and in these months overcast skies are less frequent than in the remainder of the year.

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THE CONSTRUCTION OF 500-MILLIBAR CHARTS FOR THE EASTERN NORTH ATLANTIC–EUROPEAN SECTOR FROM 1781

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Summary. A method of constructing 500-mb charts for the eastern North Atlantic–European sector using historical daily weather maps from 1781 and inferred 1000–500-mb thickness patterns is described together with an illustrative example. The significance of extending a series of 500-mb charts over the past two centuries is discussed in relation to long-range forecasting techniques.

Introduction. Some uses of the series of daily synoptic weather maps for the eastern North Atlantic–European sector being constructed by the writer from 1 January 1781 have recently been discussed;[1] preliminary findings concerning British Isles Weather Types and *PSCM* indices for the 4-year phase 1781–84 have also been presented.[2,3] A further synoptic use to which these charts could be subjected would be the construction of 500-mb contour charts using inferred 1000–500-mb thickness patterns.

The thickness of the 1000–500-mb layer has been synoptically analysed by European meteorological services on a routine basis since the introduction of reliable upper-air data in the 1930s, and the synoptic climatology of 1000–500-mb thickness lines is now adequately documented over the northern hemisphere for the past 30 years. Monthly charts giving mean and extreme maximum and minimum positions of standard thickness lines have been published for the period 1951–66.[4]

The various sources of surface data that are available from the latter part of the eighteenth century[5,6,7,8] allow a confident analysis to be made of daily surface pressure patterns over the eastern North Atlantic–European sector from 1781, with standard isobars drawn at 4-mb intervals.

The object of this discussion is to show that it would be a feasible and worth-while proposition to construct a series of 500-mb charts using historical daily synoptic weather maps from 1781 employing a method adapted from the well-established technique of preparing forecast thickness patterns.[9]

Method. The notation S_1, S_2; L_1, L_2; and T_1, T_2 refers to two succeeding historical daily charts at 14 h and indicates respectively surface, 1000-mb and 1000–500-mb thickness patterns.

Construction of 1000-*mb chart.* A reasonable approximation to the contours on the 1000-mb chart could be obtained from selected surface isobars on the historical surface maps using the formula:

$$1000\text{-mb height} = \frac{3(p - 1000)}{4} \text{ geopotential decametres}$$

where p is the surface pressure in millibars.[4]

Construction of 1000–500-*mb chart.* The 1000–500-mb thickness pattern could be inferred by employing a combination of techniques:

(a) Spot values of the 1000–500-mb thickness at a network of points could be obtained as follows:

  (1) By assuming a saturated adiabatic lapse rate in the 1000–500-mb layer, an approximation of the 1000–500-mb thickness could be deduced from the relationship between total thickness and wet-bulb potential tempera-ture, theoretical 1000-mb wet-bulb values having been extrapolated from actual surface temperatures and pressures plotted on the historical weather maps.

  (2) By using relationships between surface temperature and 1000–500-mb thickness determined from present upper-air data. Since thickness lines are advected as if embedded in the 1000-mb geostrophic wind field, an allowance for air-mass changes could be made by classifying the temperature/thickness relationship at each upper-air station according to the 1000-mb wind direction. The relationship could then be applied

to a network of actual or inferred surface temperatures and 1000-mb winds on S_1, S_2 and L_1, L_2, etc. corresponding to the locations of present upper-air stations.

(b) Thickness lines could be advected from T_1 to T_2 according to the geostrophic wind field of L_1, taking into account, as far as possible, continuity of frontal and air-mass analysis from S_1 to S_2, nature of underlying surfaces and physical and dynamical processes.

(c) The resulting thickness pattern could be checked against the inferred spot-thickness values plotted on T_2, see (a), and adjustments made if necessary.

(d) The employment of statistically derived relationships between certain 1000–500-mb thickness lines and surface weather, for example, critical total-thickness values associated with the change-over from liquid to frozen forms of precipitation,[10] and those values related to the position of the Polar Front at different seasons.

(e) 1000–500-mb thickness patterns associated with characteristic surface situations could be inferred.

(f) Regions of intensification and discontinuity in the thickness gradient could be located with reference to positions of surface fronts.

(g) Adjustments could be made to ensure a mutual consistency between the 1000-mb and 1000–500-mb topographies from a knowledge of the actual intensification and movement of surface weather systems as described by the Sutcliffe Development Theorem.

(h) Time continuity could be maintained of daily positions of thermal troughs and ridges, cold and warm pools.

(i) The positions of thickness lines could be compared with the appropriate monthly means and extremes from the present synoptic climatological record, to ensure that exceptional displacements had not been made unless it was considered that the weather situation had been of an extreme type.

Construction of 500-*mb chart.* The 500-mb contour chart could now be constructed by gridding the 1000-mb contours with the 1000–500-mb thickness lines.

General survey. Finally all three constructed charts could be subjected to a general review to ensure, as far as possible, that the resulting patterns have an overall consistency in the light of synoptic experience with three-dimensional atmospheric circulations.

An illustrative example. By employing the method outlined above a three-dimensional representation of the synoptic situation for 28 December 1783 has been constructed (see Plate II).

Synoptic situation. From 27 to 28 December 1783 a depression moved slowly east from the Bay of Biscay into central France. A very cold east-north-easterly airstream covered the British Isles. On the 29th pressure rose over the British Isles and western Europe with the low-pressure system being transferred into northern Italy.

Weather. Occasional wintry showers occurred on the 27th with snow becoming continuous over south-eastern England on the 28th. Very mild air covered southern France on the 28th whilst clear but extremely cold conditions over Scandinavia were spreading south-west; — 15°C was reported at both Stockholm and Spydberg, near Oslo, at 14 h. Heavy snow, freezing rain and glazed frost occurred in the frontal zone running west to east over the mainland of Europe.

1000–500-*mb thickness pattern.* The main features of the inferred 1000–500-mb thickness pattern are a confluent thermal ridge over France with a strong thermal gradient in the forward area and a cold pool over Scandinavia. The pattern closely resembles the characteristic thickness pattern associated with the formation of a warm-occlusion secondary depression or warm-front wave.[11]

Conclusion. Three-dimensional studies of the general circulation support the view that temporal and spatial changes of climate over the surface of the earth are related to variations of flow in the upper troposphere. Investigations of atmospheric circulation anomalies are proving to be of great value with present techniques of long-range forecasting. A recent analysis of monthly mean 500-mb charts for the period 1945–72 has shown that circulation anomalies at the 500-mb level are of significant importance with the prediction of temperature and rainfall on the 15-day and 30-day and possible seasonal time scales.[12]

Studies of climatic change during the secular period have also suggested that anomalous modes of atmospheric circulation may have longer periods of characteristic persistency ranging over time scales of yearly to decadal dimensions. An attempt to construct 500-mb charts using inferred 1000–500-mb thickness patterns from historical weather maps before the routine synoptic analysis of upper-air charts would therefore have prospects of considerably lengthening the synoptic record of the three-dimensional representation of the atmosphere in which the search for monthly, seasonal and longer-period analogues could be extended. The determination of the frequency, duration and nature of possible long-term anomalies of atmospheric circulation over the past two centuries would provide a greater scope for anticipating the character of climatic changes in the future.

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REVIEWS

Waves in the atmosphere, by E. E. Gossard and W. H. Hooke. 250 mm × 170 mm, pp. xv + 456, *illus.*, Elsevier Scientific Publishing Company, P.O. Box 211, Amsterdam, The Netherlands, 1975. Price: Dfl. 156.00.

The main title of this book 'Waves in the atmosphere' is disappointingly inaccurate and much broader in scope than the actual subject matter, which is accurately described by the sub-title 'Atmospheric infrasound and gravity waves —their generation and propagation'. The authors deal with waves whose properties are dominated by the effects of atmospheric compressibility and gravitational stratification and only include first-order effects of the earth's rotation. Large-scale waves such as atmospheric tides, Rossby waves and Kelvin waves are not dealt with but some of their essential characteristics are noted when developing the basic equations.

The chapter titles are: Introduction; The fundamental equations; Relationships between field variables; Wave equations and dispersion equations; Some boundary value problems; Dynamic stability of atmospheric waves; Wave propagation in a dissipative atmosphere; Mountain lee waves; Infrasound; Progressive bouyancy waves in the lower atmosphere; Waves in the upper atmosphere.

The basic equations are derived from first principles in a clear and careful manner which should make the book self-contained and lead owners of the book to use this section as a basic text for other purposes. Readers with little experience in atmospheric physics or fluid mechanics should benefit from this approach but more experienced readers who jump to a particular point in the book may have to search backwards to confirm aspects of notation which have not been re-emphasized after their initial thorough introduction. Having developed the basic equations the authors make their way in the clear and systematic fashion indicated by the chapter titles through to general and atmospheric models involving gravity waves and infrasound. The material centres around the troposphere with a concise discussion of effects in the upper atmosphere. A good physical understanding is coupled with followable mathematics and it is a delight to be lead so easily from the basic equations to the most recent literature.

The latter part of the book considers observations of gravity waves and infrasound in the atmosphere and goes on to discuss the possible sources of the waves. Faced with the very extensive literature on mountain lee waves the authors present a short selective review which fits in well with the rest of the book. It contains some detailed examples and a discussion of momentum transport by mountain lee waves. The chapters on infrasound, progressive buoyancy waves,

and waves in the upper atmosphere include a detailed discussion of the methods of observation which includes both the instrumentation and some of the more specialized aspects of data processing. A particularly noteworthy aspect of the book is the attention given to possible sources of waves, a vital aspect not always considered in sufficient detail.

In all, this first-class book will form an excellent basis to the study of atmospheric gravity waves and infrasound and, in the absence of another comparable book, will be especially welcome. It does not require much background in atmospheric sciences or fluid mechanics and its clear, well referenced workings from the basic equations to the recent literature will make the book equally valuable to the experienced worker and to the student.

P. J. MASON

Physics of drop formation in the atmosphere, by Yu. S. Sedunov. 245 mm × 175 mm, pp. x + 234, *illus.,* (translated from the Russian by Israel Program for Scientific Translations, Jerusalem), John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1974. Price: £8.40.

The original volume of which this is a translation was published in Russia in 1972, but this delay is not significant in what has been for some time a relatively slow growth field.

There are three reasons which make it unlikely that this book will be purchased by more than a very few: it is a highly specialist work, it is difficult to read, and it is unrealistically priced.

The author claims that the book is 'not a survey of achievements in this field but rather an attempt at constructing a systematic model of growth by condensation of droplet population with reference to atmospheric features' so the book must be judged to some extent on these terms.

In fact, the treatment is highly theoretical and mathematical with relatively minor reference to the results and methods of laboratory or atmospheric studies. The comprehension of the work is hindered by an undisciplined riot of nonstandard mathematical symbols used in very cumbersome equations. This is a pity, for the book is the end product of an immense amount of work which discusses many aspects of droplet growth very thoroughly.

After a brief introduction, the theory of growth of a single droplet by condensation is discussed with particular reference to the relaxation times of the various processes involved, and the limitation of Fickian diffusion theory within one mean free path of the droplet surface. Processes thought to be unimportant are listed; the list includes radiative transfer, now thought to be important in some situations.

The next chapter discusses condensation nuclei (CN) beginning with a brief survey of observational data on their size distribution and chemical composition, followed by a discussion of the equilibrium radius of a CN and the variation of CN spectra with increasing humidity. The author's labelling of a particle as a CN or a droplet depending on whether its radius is less than or greater than the critical value for a particular supersaturation does not seem to be a fruitful one to this reviewer.

Chapters 4 and 5 discuss the interaction of populations of growing droplets with supersaturation, and demonstrate the well-known narrowing of the droplet spectrum observed in many numerical models but not in the atmosphere—a discrepancy, the possible cause (or causes) of which is still controversial.

The book finishes with two chapters on the effect of turbulence on fields of temperature, liquid water content and supersaturation, and concludes that turbulence *within* the cloud considerably broadens the droplet spectrum—a view not shared by most cloud physicists.

There is no discussion of droplet growth by coalescence, which the title of the book might lead some readers to expect.

W. T. ROACH

Advances in satellite meteorology 2, N. K. Vinnichenko and A. G. Gorelik (editors). 245 mm × 170 mm, pp. vi + 148, *illus.*, (translated from the Russian by Israel Program for Scientific Translations, Jerusalem), John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1974. Price: £15.75.

This slim volume is a translation of a collection of papers which were originally published, under the title 'Satellite meteorology', in the U.S.S.R. in 1972. Both present and original titles are misleading. Those who expect to find a general treatise on satellite meteorology will be sadly disappointed while those with interests in microwave and Doppler radar techniques, who might find this book useful, could be excused for overlooking it.

The papers can be grouped under five general subject headings: microwave emission from rain and water vapour (six papers); microwave observations made from the satellite COSMOS-243 (two papers); emission from the atmosphere and clouds in the 8–12-μm band (two papers); procedures for interpreting Doppler radar data (three papers); the use of satellite imagery for sea-ice surveys (one paper). Within each subject grouping the papers are only loosely related. No general review papers are included.

The papers on microwave emission are mostly of a rather detailed practical nature. They summarize the results from series of ground-based microwave-emission observations (wavelength range 0·8 to 3·2 cm) aimed at improving relationships between emission measurements and atmospheric conditions. The results might also provide a partial basis for the design of satellite microwave radiometer experiments. Some of the tables and diagrams may be useful for reference purposes. COSMOS-243, which was active in orbit for four days in September 1968, carried a set of microwave radiometers. Some of the data from this experiment are presented in a semi-quantitative manner which fails to illustrate the potential usefulness of a scanning microwave radiometer. The ground-based measurements of atmospheric and cloud emission in the 8–12-μm region were made in a single wide spectral passband. Although reasonable values for the emissivity of cirrus are obtained, little information is given on the data used in the calculations and there is no mention of continuum absorption. The Doppler radar papers expound methods of data analysis which are claimed

to provide improvements in the accuracy of derived vertical velocities. The papers are all rather dated; the work was done in or before 1970 and none of the references to the literature are more recent than 1970.

This volume cannot be recommended to the general reader and its value as a reference work is limited.

<div align="right">D. E. MILLER</div>

NOTES AND NEWS

Dr R. Hide—Special merit promotion to Chief Scientific Officer

It is a pleasure to record that Dr Raymond Hide has been granted promotion to Chief Scientific Officer under the scheme which permits the promotion of scientists of exceptional ability without any consequential change in their administrative responsibilities. Dr Hide was appointed to the Meteorological Office in 1967 as Deputy Chief Scientific Officer in order to establish, within the Office, a laboratory for fluid dynamic experiments with rotating fluids. This was a field of research in which Dr Hide had already established himself as one of the world's leading authorities by the experiments which he initiated in Cambridge in the early 1950s and continued subsequently at Chicago, at Durham and as Professor at the Massachusetts Institute of Technology.

Since Dr Hide joined the Meteorological Office he has led a small group of scientists and his laboratory has become one of the principal centres for the study of geophysical hydrodynamics. Under carefully controlled laboratory conditions, it has been possible to reproduce motions characteristic of phenomena of the atmosphere and oceans including the atmosphere of other planets. By varying the experimental conditions remarkable insight has been obtained into the fundamental dynamical factors controlling many different aspects of motions on the surface of planets and in their interior. Dr Hide's penetrating studies have had an important influence on the development of ideas on the nature of geophysical phenomena as diverse as Jupiter's red spot and the variations of the earth's magnetic field as well as on the circulation of the atmosphere.

<div align="right">J. S. S.</div>

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LETTER TO THE EDITOR

Comments on 'The tornadoes of 26 June 1973'

Dr Fenner[1] concluded that the best prediction of severe storm movement was the mean wind shear direction. Spillane and McCarthy[2] give a theoretical basis for estimating trajectories in the downdraught of a thunderstorm and temperatures along these trajectories. They conclude that 'the organization and thus the

severity of the storm depends critically on the shear of the wind from the surface to about 450 mb'. They also state that 'a criterion for stability of the mature stage is that equal quantities of air are brought into the open system by the downdraft and updraft'.

Colquhoun,[3] independently of Dr Fenner and on the basis of Spillane and McCarthy's work, postulated that the 'maximum storm intensity is reached when it moves with a velocity giving the maximum rate of inflow of air to the updraft/downdraft system from those components of the environmental flow parallel to the storm path'. By using the wind profile in the environment of the storm between the surface and 450 mb the velocity of the severe storm may be estimated. Testing the theory on nine storms which occurred in Australia and in the U.S.A. gave encouraging results. Comparison of the observed and forecast severe storm velocities showed an average absolute direction error of 5·6 degrees and average absolute speed error of 1·5 knots.

Using this method on the data in Figure 7 of Whyte[4] gives estimates of the severe storm velocity of 240° 16 kt based on Crawley winds and 220° 15 kt based on Hemsby winds.

In most cases the direction of severe storm motion produced by this method will be similar to Dr Fenner's 'mean wind shear direction'.

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